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data bit stream | attenuation (dB)
signal to noise ratio (S/N) | error recorder

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Bit error rate (BER) bench testing of digital radios in a back-to-back mode essentially determine hardware characteristics independent of external anomalies such as impulse noise, fading, and interfering signals. This method employs the statistic of a characteristic theoretical curve of a long term BER versus received signal level (RSL). The attenuation is initially set to produce a BER of approximately 10^{-4} at a corresponding RSL. When this point on the curve is statistically valid long term BERs can be predicted to correspond with the RSL.

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US ARMY TEST AND EVALUATION COMMAND
TEST OPERATIONS PROCEDURE

DRSTE-RP-702-105 1 September 1981
Test Operations Procedure 6-2-570
AD No. A104573

AD A104573

STANDARD BIT ERROR RATE (BER) VERSUS RADIO RECEIVED SIGNAL LEVEL TESTING

1. SCOPE

Bit error rate (BER) bench testing of digital radios in a back-to-back mode essentially determines hardware characteristics independent of external anomalies such as impulse noise, fading, and interfering signals. This method employs the statistic of a characteristic theoretical curve of a long term BER versus received signal level (RSL). The receiver attenuation is initially set to produce a BER of approximately 10^{-4} at a corresponding RSL. A suitable number of errors should be counted at this point to insure a required level of confidence (Crow[1]) and to produce a sufficient accuracy so that the system's theoretical bit error function curve can be shifted laterally to fit through this point. By taking an additional point at 10^{-6} BER, a check can be made to assure that the equipment is operating properly. This statistical methodology used to test BER will save testing time by 4 or 5 orders of magnitude. Experimental and theoretical validation of this technique by L.C. Schooley and G.R. Davis of the University of Arizona is presented in Volume II of their report.[2]

1. Crow, E.L., "Confidence Limits for Digital Error Rates", US Department of Commerce, Office of Telecom., November 1974 (OTP 74-51).

2. L.C. Schooley and G.R. Davis, Digital Communications Systems: Test and Evaluation Studies, Volume II (AD No. A097123), Engineering Experiment Station, College of Engineering, The Unversity of Arizona, 31 August 1979 (Vol 1, AD No. A097122).

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2. FACILITIES AND INSTRUMENTATION

2.1 Facilities. A radio test facility equipped with test benches complete with power sources, required tools, required test equipment, and accessories such as connectors, clips, and test cables.

2.2 Instrumentation and Equipment

Item	Requirement/Tolerance
Data generator	A data generator capable of producing the data bit stream required by the radio system under test and the bit pattern of interest.
Data error detector	Error detector must be capable of detecting and conducting a bit-by-bit analysis of the transmitted bit stream.
Attenuator	As required.
Radio transmitter, under test	
Radio receiver, under test	

2.3 Suggested Equipment

Item	Equipment
Attenuator	HP382 or equivalent, 175 dB maximum attenuation.
Data generator	HP3760 and 3762.
Error detector	HP3761 and 3763
Data generator/error detector	HP1645, HP3780, Aydin 604, or equivalent Data Test Sets.

3. PREPARATION FOR TEST

3.1 Facilities. Assure facilities are available.

3.2 Equipment. Assemble instrumentation and radios to conform with figure 1, (page 5).

3.3 Instrumentation. Connect the data generator to the radio transmitter. Connect the attenuator between the radio transmitter and the radio receiver. Connect the output of the radio receiver to the data error detector for error detection and recording.

3.4 Data Required. Record the following:

3.4.1 Test Item. Item serial number, nomenclature, and characteristics as required.

3.4.2 Instrumentation. Type, model, serial number, manufacturer, and calibration data for each instrument.

3.4.3 Personnel Data. Technician's name, grade, and MOS/series.

4. TEST CONTROLS

a. Set up instrumentation with the test item in an appropriate test facility (TF).

b. Set up the radio transmitter and receiver and check them out to be in proper operating condition.

c. Adjust the data generator to provide a digital bit pattern of appropriate size and characteristics.

d. Conform the analysis of the error rate data points to standard statistical guidelines. (See Crow 1)

5. PERFORMANCE TESTS

a. Adjust the attenuation in test set-up (fig. 1) to a received signal level (RSL) that produces a bit error rate (BER) of 10^{-4} IAW reference 1, Appendix B.

b. Vary the RSL to provide a BER of 10^{-6}. This will give a second point on the BER versus RSL curve. The systems theoretical BER (vs) RSL curve should now fit through these measured points.

c. Adjust attenuation of the radio received signal level to develop a BER of 10^{-4} and then to a setting to obtain a BER of 10^{-6}. The systems RSL versus BER theoretical curve (theoretical curve is based on the systems modulation scheme employed) should fit through the two BER points measured. The theoretical curve will probably have to be shifted "laterally an amount fixed by the equipment quality." (L. C. Schooley and G. R. Davis[3])

3. Schooley, L.C. and G.R. Davis, "Instrumentation and Methodologies for Testing and Evaluation of Digital Communications Systems and Equipment," Technical Report, Engineering Experiment Station, University of Arizona, Tucson, Arizona, 15 May 1977. (AD B020427)

6. DATA REDUCTION AND PRESENTATION

a. Present the data on a curve representing bit error rate versus receive signal level.

(1) Bit error rate (BER) along the ordinate.

(2) Received signal level (RSL) along the abscissa.

(3) Bit error rate is the total number of errors detected, divided by the total number of bits received over the same time period.

(4) Received signal level (RSL) is the level in dBm of the received signal.

(5) Plot a curve of BER vs RSL as in figure 2.

b. Extrapolate from the plotted curve the received signal level which will produce the desired or specified bit error rate.

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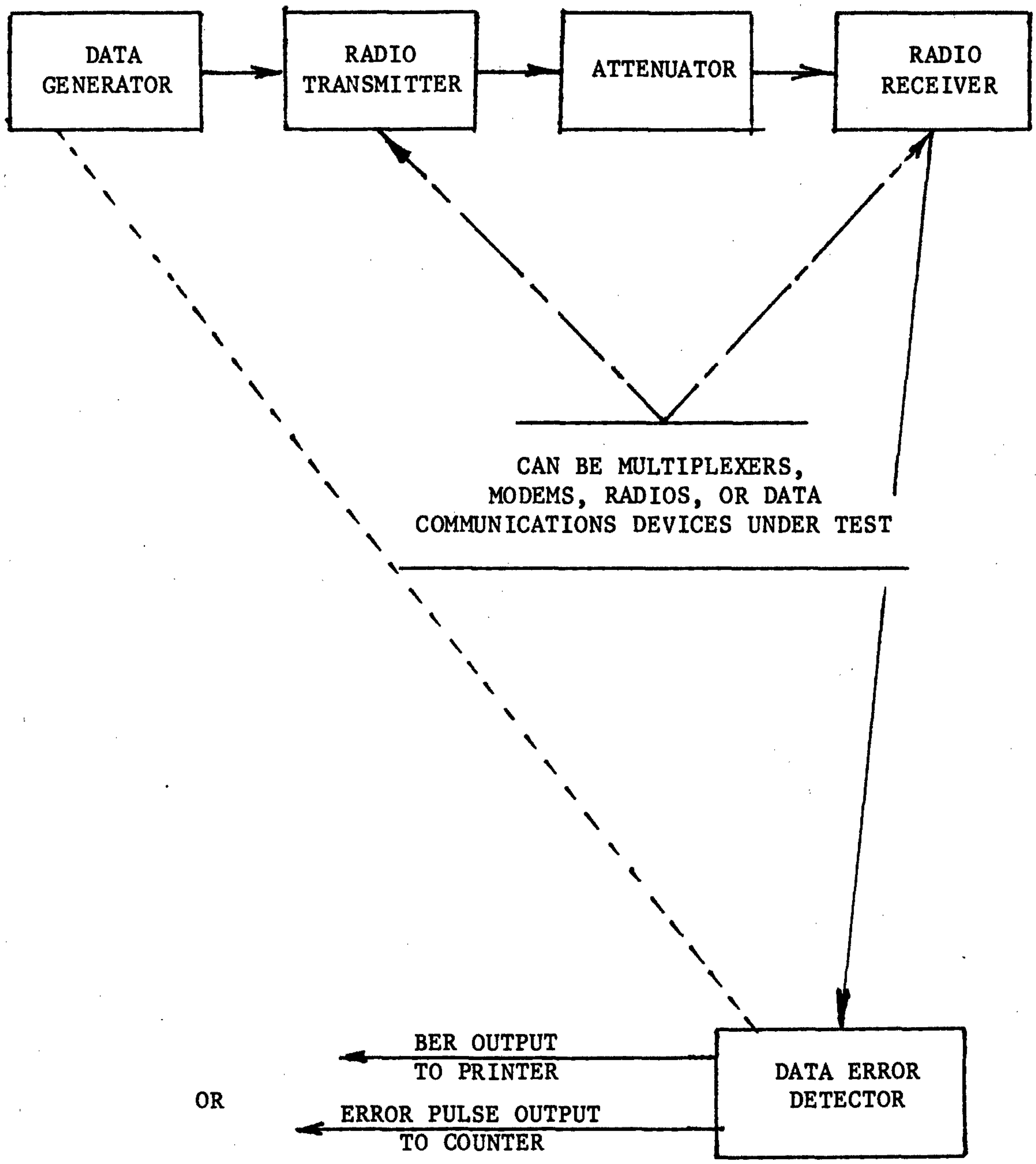

Figure 1. Measurement of BER or errors for bench test.

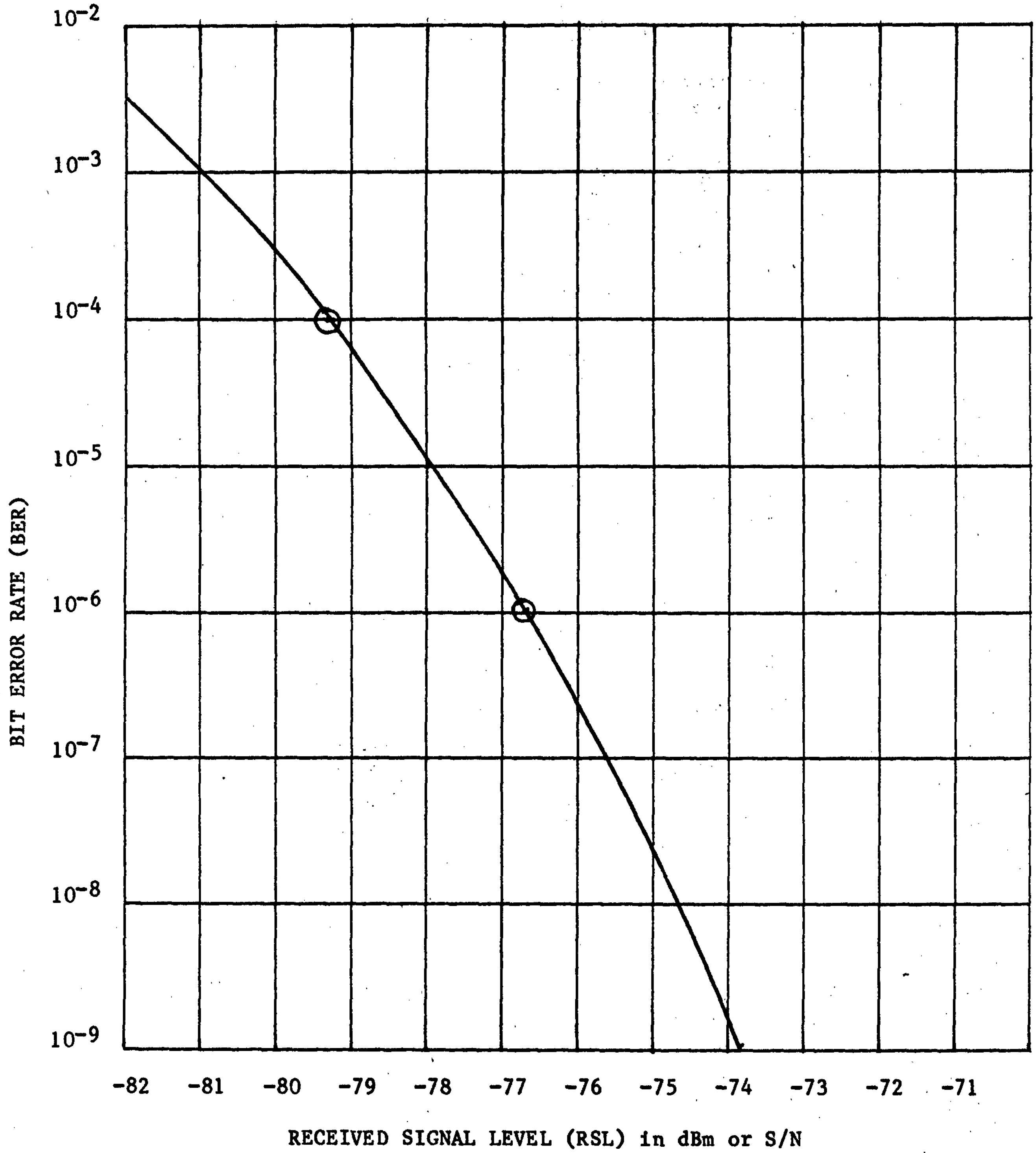

Figure 2. Bit error rate versus received signal level.

APPENDIX A. REFERENCES

1. Crow, E.L. "Confidence Limits for Digital Error Rates", US Department of Commerce, Office of Telecom, November 1974 (OTP 74-51).

2. L.C. Schooley, G.R. Davis, Digital Communications Systems: Test and Evaluation Studies, Volume II (AD No. A097123), Engineering Experiment Station, College of Engineering, The University of Arizona, 31 August 1979 (Vol 1, AD No. A097122).

3. L.C. Schooley, G.R. Davis, "Instrumentation and Methodologies for Testing and Evaluation of Digital Communications Systems and Equipment" Technical Report, Engineering Experiment Station, University of Arizona, Tucson, Arizona, 15 May 1977. (AD B020427)

4. L.C. Schooley, G.R. Davis, Final Report on Testing and Evaluation of Digital Communciation Systems and Equipment, 15 June 1977. (AD B020428)

5. L.C. Schooley, G.R. Davis, Extrapolation of Bit Error Rate Measurements: Experimental Results (Preliminary Report), 15 September 1978. (AD A059836)

APPENDIX B

CHECKLIST

STANDARD BIT ERROR RATE (BER) TESTING

Facility is available.	____________
Instrumentation is calibrated.	____________
Instrumentation data recorded.	____________
Name, Grade, and MOS of person taking data recorded.	____________
Security measures instituted.	____________
Thermal equilibrium obtained.	____________
Required test data recorded.	____________
Feasibility/Compatibility of data generator/detector and radio.	____________
Data reduced.	____________

APPENDIX C

BIT ERROR RATE DATA

dBm Attenuation	Sample Period(s) (Seconds)	Bit Rate(R)	Number of Errors (E)	Bit Error Rate (BER = E/R*S)

APPENDIX D

D.1 Confidence Limits for BER

The following information has been summarized from Crow [1]. Only those details necessary to understand the use of the tables for the examples has been included. It is suggested that Crow's complete work be studied by anyone who intends to apply the method.

It is assumed that the system under observation suffers errors which occur independently with probability p. The purpose is to determine as accurately as possible the true BER (p) of a system if c errors are observed in a sample of n bits. It is well known that $\bar{p} = c/n$ is the single best estimate and will approach the true p as n increases without bound. However for finite n, p is a random variable and may differ widely from the true value.

If p remains constant during the total number of samples n, and if the probability of error in each bit is independent of whether any other errors have occurred, then the probability of c errors in n bits is governed by the binomial distribution. It is then possible to calculate confidence limits for p.

By confidence limits is meant: for a given number of errors c in a sample number of bits n, an interval about $\bar{p} = c/n$ can be determined within which the true value of p lies with a given percent of confidence. For example, assume a sample of 10^6 bits is taken and 8 errors are observed, and we wish to be 90 percent certain of the range of the true value of the BER. Referring to table D.1 we find the number 8 under the column c; then moving across to the 90 percent confidence level columns we find the factors L = 4.0 and U = 14.4. We can then be 90 percent certain that the true BER lies between $L/n = 4/10^6 = 4 \times 10^{-6}$ and $U/n = 14.4/10^6 = 1.44 \times 10^{-5}$.

When the test is terminated after a given number of bits has been received and then the number of errors counted, the test is termed binomial sampling and the confidence limits are determined as above. If the test is to be terminated after a given number of errors is counted then the test is termed inverse binomial sampling. In this case, since the test is stopped on an error, the confidence interval is biased. Crow has shown that in this case the lower limit remains the same, however, the upper limit is taken from c-1. In the example above, if the test were stopped after 8 errors were counted and it was then determined that the total number of bits sent was 10^6, the lower limit would be determined from c = 8, however the upper limit would be determined from c - 1 or 7. The confidence limits would then be:

$4.0/10^6 = 4 \times 10^{-6}$ and $13.1/10^6 = 1.31 \times 10^{-5}$.

D.2 Determination of Length of Test

Figure D.1 gives some statistical sample size relationships. The curves are a plot of the percent half-length of the confidence interval versus the number of errors for given levels of confidence. A 30 percent half-length confidence interval would mean that the interval would extend $0.3\bar{p}$ on either

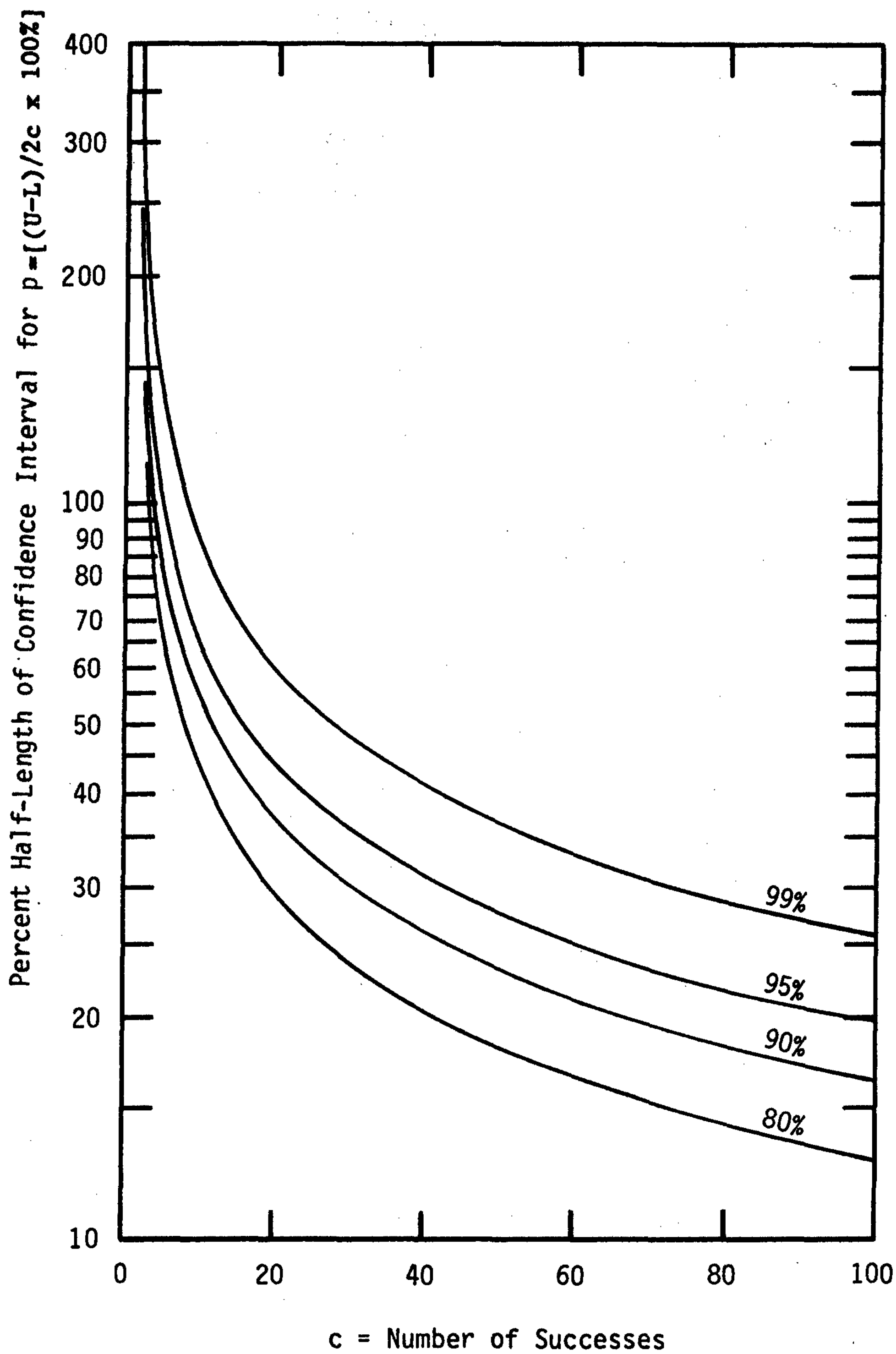

Figure D-1. Relative precision in estimating p from large samples when number of successes is prescribed and $c/n \leq 0.1$.

side of $\overline{p}$ (for binomial sampling; inverse binomial sampling is slightly biased). An example of the use of the curves might be: suppose it is desired to determine a 50 percent half-length interval with 95 percent confidence. The curves show that approximately 13 errors would have to be counted. This then is the stopping point for an inverse binomial sampling test. To determine the desired length of a binomial sampling test it is necessary to make preliminary estimate of the actual BER. For example if the BER were suspected to be approximatly 10^{-6}, then the number of samples required for the above case would be estimated to be $n \doteq c/p = 13/10^{-6} = 13 \times 10^{6}$ bits.

D.3 <u>Use in Sequential Testing</u>

Crow suggested the possibility of proceeding in a sequential manner but did not detail this method of testing. (See reference 1, Appendix A.)

In Crow's determination of confidence limits it is assumed that the probabilities of error of the first and second kind are equal, i.e., = , and this is usually appropriate for the communications testing problem. Then the confidence level for the determined interval is 1 - 2 . For example for a 90 percent confidence level (= = 0.05) the probability that the true BER is less than the lower limit which is 0.05 and the probability that the true BER is greater than the upper limit is also 0.05. As will be seen, these upper and lower limits will be interpreted as our decision thresholds A and B.

Example 1 uses the confidence limits in the following manner. After 10^4 bits are received we see from the table that if 3 errors are counted the 80 percent confidence limits are $1.1. \times 10^{-4}$ and 5.3×10^{-4}. We are then 90 percent sure that the BER is greater than 1.1×10^{-4} and the item is rejected. However if less than 3 errors are counted no conclusion can be reached. Three errors is then our lower threshold B, but an upper threshold cannot yet be determined.

After 3×10^4 bits have been received we can determine both a lower and upper bound. If 6 errors have been counted the 80 percent confidence interval is $3.15/3 \times 10^4 = 1.05 \times 10^{-4}$ and $10.5/3 \times 10^4 = 3.5 \times 10^{-4}$ and we are therefore 90 percent certain the BER is greater than 1.05×10^{-4}. On the other hand, if no errors have been received the 80 percent confidence interval is between 0 and $2.3/3 \times 10^4 = 0.77 \times 10^{-4}$. We can therefore be 90 percent certain that the BER is less than 0.77×10^{-4}.

Examples 2 and 3 utilize inverse binomial sampling, therefore the upper and lower boundaries are determined from the table in terms of the total number of bits received.

Table D.1. Factors for Confidence Limits for a Proportion (or Error Rate or Probability of an Error) if Sample Size $\geq$40 amd Observed Proportion $\geq$0.1

L = factor for lower limit
U = factor for upper limit
n = prescribed sample size
c = observed number of errors ($\geq$0.1n)

To get limits to 1-digit accuracy (2-digit for n$\geq$10,000), simply divide factor (L or U) by n.

To get limits to 2-digit accuracy for 40$\leq$n$\leq$10,000), divide L by n-(c-1-L)/2 and U by n+(U-c)/2.

Confidence Level	80%		90%		95%		99%	
c	L	U	L	U	L	U	L	U
0	.000	2.30	.000	3.00	.000	3.7	.0000	5.3
1	.105	3.9	.051	4.7	.025	5.6	.0050	7.4
2	.53	5.3	.36	6.3	.242	7.2	.103	9.3
3	1.10	6.7	.82	7.8	.62	8.8	.34	11.0
4	1.74	8.0	1.37	9.2	1.09	10.2	.67	12.6
5	2.43	9.3	1.97	10.5	1.62	11.7	1.08	14.1
6	3.15	10.5	2.61	11.8	2.20	13.1	1.54	15.7
7	3.9	11.8	3.3	13.1	2.81	14.4	2.04	17.1
8	4.7	13.0	4.0	14.4	3.5	15.8	2.57	18.6
9	5.4	14.2	4.7	15.7	4.1	17.1	3.13	20.0
10	6.2	15.4	5.4	17.0	4.8	18.4	3.7	21.4
11	7.0	16.6	6.2	18.2	5.5	19.7	4.3	22.8
12	7.8	17.8	6.9	19.4	6.2	21.0	4.9	24.1
13	8.6	19.0	7.7	20.7	6.9	22.2	5.6	25.5
14	9.5	20.1	8.5	21.9	7.7	23.5	6.2	26.8
15	10.3	21.3	9.2	23.1	8.4	24.7	6.9	28.2
16	11.1	22.5	10.0	24.3	9.1	26.0	7.6	29.5
17	12.0	23.6	10.8	25.5	9.9	27.2	8.3	30.8
18	12.8	24.8	11.6	26.7	10.7	28.4	8.9	32.1
19	13.7	25.9	12.4	27.9	11.4	29.7	9.6	33.4
20	14.5	27.0	13.3	29.1	12.2	31	10.4	35
21	15.4	28.2	14.1	30.2	13.0	32	11.1	36
22	16.2	29.3	14.9	31.4	13.8	33	11.8	37
23	17.1	30.5	15.7	32.6	14.6	35	12.5	38
24	18.0	31.6	16.6	33.8	15.4	36	13.3	40

Confidence Level	80%		90%		95%		99%	
c	L	U	L	U	L	U	L	U
25	18.8	33	17.4	35	16.2	37	14.0	41
26	19.7	34	18.2	36	17.0	38	14.7	42
27	20.6	35	19.1	37	17.8	39	15.5	43
28	21.5	36	19.9	38	18.6	40	16.2	45
29	22.3	37	20.7	40	19.4	42	17.0	46
30	23.2	38	21.6	41	20.2	43	17.8	47
35	27.7	44	25.9	46	24.4	49	21.6	53
40	32.1	49	30.2	52	28.6	54	25.6	59
45	36.6	55	34.6	58	32.8	60	29.6	65
50	41.2	60	39.0	63	37.1	66	33.7	71
55	46	66	43	69	41	72	38	77
60	50	71	48	74	46	77	42	83
65	55	77	52	80	50	83	46	89
70	60	82	57	85	55	88	50	95
75	64	87	61	91	59	94	55	100
80	69	93	66	96	63	100	59	106
85	73	98	70	102	68	105	63	112
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